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Citation for published version (APA):

Tiwale, S., Rusca, M., & Zwarteveen, M. (2018). The power of pipes: mapping urban water inequities through the material properties of networked water infrastructures: The case of Lilongwe, Malawi. *Water Alternatives*, 11 (2), 314-335. <http://www.water-alternatives.org/index.php/alldoc/articles/vol11/v11issue2/439-a11-2-6>

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Tiwale, S.; Rusca, M. And Zwarteveen, M. 2018. The power of pipes: Mapping urban water inequities through the material properties of networked water infrastructures - The case of Lilongwe, Malawi. Water Alternatives 11(2): 314-335



The Power of Pipes: Mapping Urban Water Inequities through the Material Properties of Networked Water Infrastructures - The Case of Lilongwe, Malawi

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ABSTRACT: Urban scholars have long proposed moving away from a conceptualisation of infrastructure as given and fixed material artefacts to replace it with one that makes it the very object of theorisation and explanation. Yet, very few studies have seriously investigated the role of infrastructure in co-shaping and mediating inequities. We use this paper to propose a way to engage with the technical intricacies of designing, operating and maintaining a water supply network, using these as an entry-point for describing, mapping and explaining differences and inequities in accessing water. The paper first proposes a methodological approach to systematically characterise and investigate material water flows in the water supply network. We then apply this approach to the case of water supply in Lilongwe, Malawi. Here, strategies for dealing with challenges of water shortage in the city have often entailed the construction of large water infrastructures to produce extra water. We show that the network's material properties direct and divert most of the extra water to elite neighbourhoods rather than to those low-income areas where shortages are most acute. Our analysis shows how social and technical processes mutually constitute each other in the production and rationalisation of this highly uneven waterscape. We conclude that further theorisations of infrastructure as providing part of the explanation for how urban inequities are produced need to be anchored in the systematic and detailed empirical study of the network-in-use. Mapping the (changing) carrying capacities of pipes, storage capacities of service reservoirs and the strategic locations of new pipe extensions – to name a few important network descriptors – provides tangible entry-points for revealing and tracing how materials not only embody but also change social relations of power, thereby helping explain how inequities in access to water come about and endure.

KEYWORDS: Urban development, water supply, material power, pipes, Lilongwe, Malawi

INTRODUCTION

I have lived here for more than fifteen years. I fetch water from this hand pump. Sometimes, I must wait here for long hours in queue. We have a kiosk [water standpipe where water is sold by individuals or community-based organisations

employed by the water utility], but it is not working. They [the water utility] constructed it two years ago, but we have not received water yet.

Judith, resident of Area 38

For the past 15 years, Judith has lived in the southern part of Lilongwe, in one of the low-income areas of the capital city of Malawi. As she is not connected to the urban water supply network through an in-house connection and because the water kiosk is not functioning, she accesses water through a hand pump. Her situation is not unique, many poor urban dwellers in cities in the global South experience difficulties in accessing sufficient domestic water of good quality. Indeed, low coverage rates and a highly differentiated access to domestic water are the norm in such cities. Water utilities in sub-Saharan Africa for instance, only serve 40-70% of the urban population, with the rest relying on self-supply or being served by small-scale water providers, ranging from mobile vendors to more sophisticated ones (Kariuki and Schwartz, 2005; Ahlers et al., 2014). As the idle water kiosk in Judith's neighbourhood shows, even a formal connection to the piped network does not necessarily mean that one has access to safe and sufficient drinking water (Jaglin, 2008; Satterthwaite, 2016). Poor unplanned settlements are the most affected by infrastructure and provisioning deficits, and most exposed to the associated health risks (Hawkins et al., 2013; Dodman et al., 2017).

These problems are well recognised by urban and water governance scholars, who increasingly advocate for incorporating the infrastructural dimension in analyses of uneven conditions of access to domestic water and of broader water (in)justice concerns in cities (McFarlane and Rutherford, 2008; Coutard and Rutherford, 2015; Addie, 2016). Recent studies have also proposed a deeper engagement with materiality of water infrastructure to capture the non-human which constitutes and exceeds the political field (Meehan, 2014; Anand, 2017; Rusca et al., 2017b). Few studies, however, engage with the technical intricacies of designing, operating and maintaining a water supply network. In this paper, we aim at advancing theorisations of materiality of networked infrastructure by proposing a methodology to trace material flows of water.

In the next section, we first provide a succinct review of debates around the role of water infrastructures in co-constituting the social world and its vast ramifications in shaping urbanisation processes and social relations, demonstrating that important critiques evoke the need of engaging with the technology of water infrastructure. The third section outlines a methodology for engaging with materiality of infrastructures. We use water supply infrastructures as a methodological device to trace uneven water flows across the city and decipher how inequity is produced through the water supply network. In subsequent sections, we apply this methodology to Lilongwe, capital of Malawi, and document how the extra water produced through the construction of dams and treatment facilities flows through the centralised water supply network in high and low-income neighbourhoods of the city up to the consumer. We show how social and technical processes associated with expansion of the water supply distribution network mutually constitute each other in the production and rationalisation of a highly uneven waterscape. Technical properties of the water supply network that appear fixed and unchangeable instead turn out to change according to political decisions on the distribution of water in the city, which systematically prioritise the demands of the economic and political elites over the basic needs of those living in growing low-income and high-density neighbourhoods.

Through the analysis of the distribution network, we provide an important part of the explanation as to why, despite 50 years of development projects to increase the supply in the city, Judith still has to access water through a hand pump. We use this finding to conclude that the systematic study of the material properties of networked water infrastructures can provide new and tangible insights on the politics of water management and the production of water inequities in the city. As doing this requires taking materiality and technology seriously, it crucially depends on the development of meaningful collaborations between social scientists and water supply engineers – those who understand and are attentive to the physical properties of infrastructures.

Last, from a policy perspective our analysis questions one of the prevailing policy responses to inadequate and unreliable domestic water supply in cities in the global South. Increasing supply through the construction of large dams is often presented as a measure invested with an extraordinary power to drastically improve the lives of urban poor. Currently, water supply dams represent about 12% of dams worldwide (McDonald et al., 2014). Beyond the apparent effectiveness of this measure, success of dams is often narrowly assessed through the quantity of the extra water they produce. Emblematic here is the World Commission on Dams Report (WCD, 2000), which measured the performance of water supply dams in terms of bulk water delivery, cost recovery and economic efficiency. Similarly, Altinbilek (2002) defines the performance of water supply dams in terms of quantity of water provided to cities in km³ per year. Our study shows that aggregating needs and availabilities at the scale of the city make it impossible to assess how (extra) water is distributed across urban spaces. The performance of dams should be measured by considering their impact on coverage and conditions of access across urban spaces. To ensure Judith and other people living in low-income settlements benefit from the increased water availability, the performance of the dam should be assessed explicitly considering how they contribute towards reducing inequities and improving access across the city, rather than the quantity of water pushed in the distribution network.

PLACING TECHNOLOGY-IN-CONTEXT: WATER INFRASTRUCTURES AND UNEVEN WATERSCAPES

Networked infrastructures are key to understanding the distribution of costs and benefits of urban development. Their socio-spatial layout not only represents a physical manifestation of a given city project, but also reflects the broader patterns of socio-economic inclusion or exclusion that characterise urbanisation processes. In this sense, networked infrastructures provide good starting points for mapping and unravelling broader concerns of (water) injustice and citizenship (McFarlane and Rutherford, 2008; Coutard and Rutherford, 2015; Addie, 2016), as they inscribe social power asymmetries on the urban landscape. Taking this recognition one step further to acknowledge how infrastructure not just reflects but also itself co-shapes identities and social relations, urban scholars have recently called for a shift from an engagement with infrastructure as hard and fixed artefacts and technological systems to one that takes it as the object of explicit analysis and theorisation. Infrastructure, they argue, is a fruitful entry-point "to think through the politics, ecology, social relations and everyday experiences of urban life" (Addie, 2016). Underlying this line of inquiry is the idea that 'the social' and 'the technical' are mutually constituted and that infrastructures are both shaped by and shape urban development (Graham and Marvin, 2001; Coutard, 2008; Monstadt, 2009; Coutard and Rutherford, 2015; Monstadt and Schramm, 2015).

Studies on urban water supply networks have been particularly influential in following this analytical approach. Urban Political Ecology (UPE) scholars have convincingly shown how infrastructural developments are shaped by political forces and in turn contribute to creating socio-ecological inequalities, including differentiated conditions of access and uneven service levels in cities (Swyngedouw, 1996, 1997, 2004; Gandy, 2003; Bakker et al., 2008; Loftus, 2009; Norman et al., 2012; Anand, 2017; Rusca et al., 2017a). Jakarta's uneven waterscape, for instance, is produced by decisions to expand the network towards modern and elite localities, bypassing lower income neighbourhoods (Bakker et al., 2008). Similarly, Contractor (2012) finds that in Mumbai, India, extensions of the formal water supply network are less likely to occur in areas where religious minorities live. These processes, it is argued, systematically work to 'dehydrate' urban slum dwellers, minorities and low-income communities (Graham et al., 2015). There is also research that has focused on the relationship between water supply dams, increased water resources availability and conditions of access, noting that enhancing supply has often reproduced rather than reduced inequalities in access to drinking water (McFarlane and Rutherford, 2008; Gandy, 2008; Bakker et al., 2008). These researches show, in the words of Bijker (2007), that water infrastructures [dikes and dams in their study] are "thick with

politics": technologies are not only shaped by powerful actors, but also exert power themselves (see also Crow-Miller et al., 2017).

Inspired by insights from Science and Technology Studies' plea for 'decentring the technology' – replacing a technologically determinist approach with one that looks at technology-in-context – urban scholars have produced a range of studies that illustrate how the performance of a technology (or infrastructure) is the effect of its interactions in networks with humans and nonhumans (Furlong, 2011; Anand, 2011, 2012; Björkman, 2014). The method of thinking of "infrastructures as living systems" (Shove, 2015: 243) draws attention to how the technology interacts with the actors that engineer, deploy, operate, and maintain it (or not) as a life support system for all – or some – citizens (Anand, 2011; Alda-Vidal et al., 2018; Graham et al., 2015; Furlong, 2015). At the core of this stream of literature is the idea that large technological systems are dynamic, flexible, heterogeneously assembled, influenced by contexts and path-dependent (Star, 1999; Hommels, 2005; ; Monstadt, 2009).

Some of the above studies suggest that technologies have a form of agency, by showing how as networked infrastructures extract, contain, channel, process, leak or distribute waters, they also shape new kinds of spaces, scales and subjectivities, thereby co-producing inequalities or differences (McFarlane and Rutherford, 2008; Meehan, 2014; Anand, 2015). Despite this suggestion, in identifying avenues for progressive change or in proposing alternative pathways to water development, critical water studies often continue privileging 'the social' as that which can (and should) be changed. Thus, they continue implicitly treating the technical as fixed, or as the given context in which the social is played out. We argue and show in this article that a more serious consideration of infrastructure and technology as co-shapers of change or development usefully multiplies avenues for change or improvement. Doing this requires in-depth engagement with the technical intricacies of designing, operating and maintaining a water supply network. We propose an approach that is anchored in the systematic tracing of material water flows through the water supply network. In the section that follows, we provide a detailed description of this methodology. We use the case of Lilongwe to show how this methodological approach can empirically substantiate understandings of the production of socio-ecological inequalities in water distribution across the urban waterscape and, in turn, contribute to a more serious analysis and theorisation of the agency of technological systems.

METHODOLOGY FOR TRACING MATERIAL (EXTRA) WATER FLOWS: FROM THE DAM TO THE TAP

An interdisciplinary analysis of networked water infrastructures entails unravelling the interdependencies between the production of urban and suburban spaces, how the water supply network is materially and discursively constructed and a description of its physical characteristics to trace where and to whom it provides which quantities and qualities of water. Operationalising this for our analysis of how water resource infrastructure development changed (patterns of) access to water, we use the concept of *extra water*. Extra water is the quantity of additional water made available for the city through infrastructural investments: the construction of a dam or the increase of water treatment capacity.

The quantification of the distribution of the extra water is a difficult task as historical data on where (areas of the city) and to whom (which customers) the extra water is distributed to are rarely available for cities in the global south. Therefore, we used the expansion of the primary distribution network¹ as a proxy indication of where and to whom the extra water flows. Our analysis is based on the hypothesis that each time extra water is made available, the distribution network needs to be expanded to accommodate it. We verified this hypothesis by analysing the historical developments of the network in

¹ The primary distribution network carries water from the treatment plant to various supply zones and consists of transport mains, service reservoirs and also booster stations in case of long stretches and/or topographic challenges.

Lilongwe and indeed established that almost every time extra water was produced, the primary distribution network was expanded.²

We first assessed the immediate expansion of the network over five decades in terms of two main technical properties: *direction* and *dimensions*. *Direction* expresses *where* (potentially) in the city the extra water flows and, therefore, which urban spaces planners are targeting for increased supply (extra water) and *who* will get this water. To trace changes in direction, we mapped the consecutive expansions of the distribution network, as well as the strategic locations of new service reservoirs³ in the network using geographic information system (GIS). *Dimensions* refer to the diameters of the transport mains⁴ and the storage capacities of service reservoirs. These reveal the carrying capacity of the network (i.e. how much water can flow in each direction). We studied the direction and dimensions of the primary distribution network by tracing the network from the water treatment plant to different supply zones. Semi-structured interviews were conducted to triangulate these data with the network operators including operation engineers, distribution supervisors, pump operators, technicians and plumbers working with Lilongwe Water Board (LWB). The historical and incremental growth of the network was studied by undertaking documentary analysis of the urban master plans, planning and appraisal documents, design reports and infrastructure assessment reports. In addition, planning and design engineers of LWB and urban planners working with Lilongwe City Council were interviewed.

Second, we assessed the influence of the direction and dimension of the network on the distribution of extra water by analysing available data of bulk water flows⁵ for the past 15 years. Water distribution across different zones was traced by analysing the water distribution report generated on a daily basis by LWB engineers. Additionally, the daily log sheets with the records of volumetric flows and pumping operations maintained by plant operators were studied. Last, while service reservoirs and transport mains determine how much water is directed to which part of the city, *the last mile of the network* determines which households in a neighbourhood do have access to this water, and which ones do not. We undertook a historical analysis of billing data to calculate per capita per day consumption, comparing before and after the increase in the storage capacity of one of the dams to determine how the extra water is distributed across the city. We triangulated these data by conducting semi-structured interviews with LWB network planners and citizens living in underserved or unserved urban areas, where condition of access had proven to be inadequate.

DEVELOPING LILONGWE'S WATER SUPPLY NETWORK: CONNECTING TO EXTRA WATER

Planning for the future capital: Water infrastructures for the 'Garden City'

Lilongwe became the capital of the Republic of Malawi in 1975, following the decision of Kamuzu Banda, the first president of the country, to relocate the capital from Zomba (Pachai, 1971) to "wipe away colonial fingerprints" from the newly established independent government (Myers, 2003). As the former Commissioner for Town and Country Planning explains, the plan was for Lilongwe to be "a national symbol and image of Malawi". It thus had to be "aesthetically appealing, pleasant and delightful to perceive, live in, work and play" (Matope 1984, see also Kayuni, 2011; Potts, 1985). This imagery of 'garden city' (Potts, 1985) was to be achieved also through the development of large

² The only exception occurred in 1984, when treatment capacity was expanded to provide 18,000 m³ of extra water per day and no changes were made in the primary distribution network.

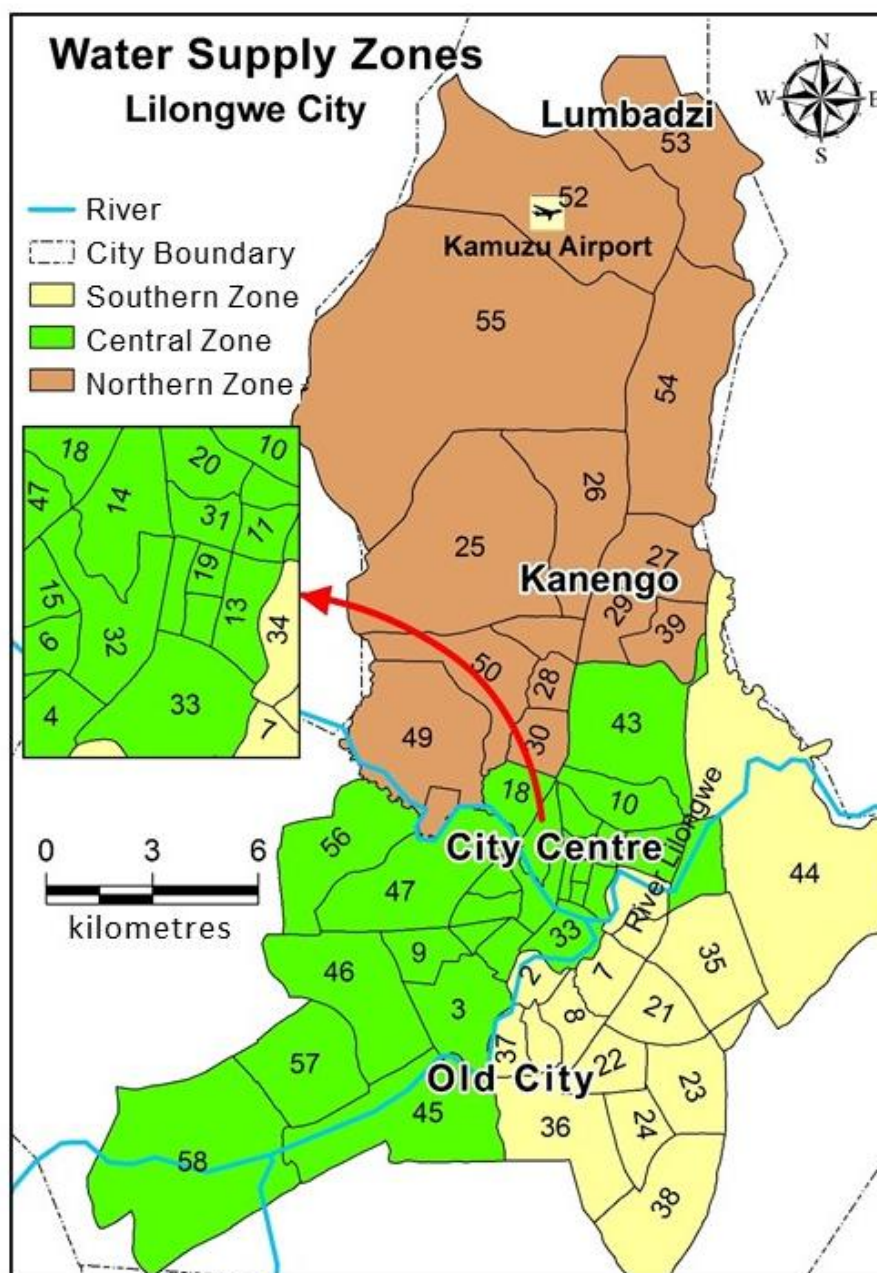
³ Service reservoirs are interim storages built in the network with the aim of acting as a buffer storage and maintaining pressure in the system.

⁴ Transport mains are the pipes with larger diameters carrying treated water from treatment plant to different zones (or parts) of the city.

⁵ Bulk flow refers to the quantity of water supplied to a particular zone.

infrastructures to accommodate the increasing water demand when, what used to be a small town of less than 20,000 inhabitants in 1966 would grow to a large urban conglomerate (Matope, 1984). Since these early stages of planning and development, the main strategy in terms of water supply planning has been to concentrate on the demands and needs of the newly constructed central area – where parliament, ministries, government offices, embassies, hotels and the commercial area were located – and the northern part of the city, hosting the airport and the industrial area.

Figure 1. Map of Lilongwe showing areas and administrative zones of Lilongwe Water Board (the numbers in the map indicate the Area numbers).



The First Lilongwe Water Supply Project (1966), financed by the Commonwealth Development Corporation of the United Kingdom, entailed the construction of a water supply dam on the Lilongwe River and a treatment plant with a production capacity of 2250 m³ per day. Kamuzu Dam-I, the largest dam in Malawi, has a live storage capacity of 4.7 Mm³ (Reuters, 1966), but given the limited treatment capacity - only 2250 m³/day of extra drinking water was produced (SAFEGE, 2002a). This extra water was distributed to the Southern and Central Zones (see Figure 3a), where two service reservoirs with a capacity of 2250 m³ each were constructed (LWB, 2008). In the Southern zone, however, the distribution network only reached the commercial part of the city in Area 1 and the elite and residential parts of Area 2, in which mainly Indian traders and businessmen were residing, while low-income areas were bypassed (see Figure 1). Since the early developments of the capital, therefore, coverage and access to drinking water have been unequal.

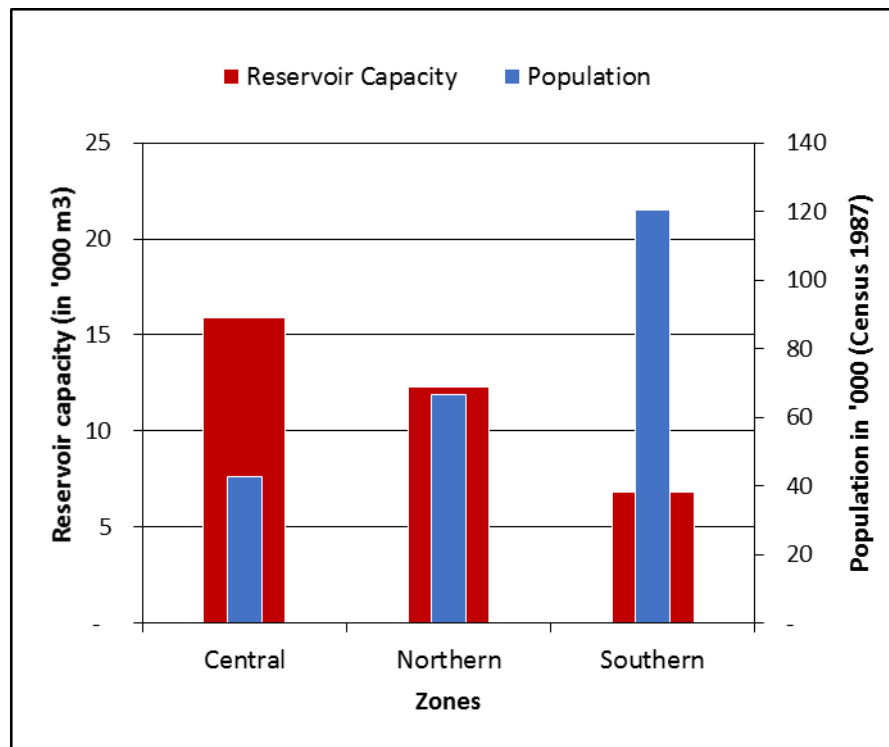
From the start, the water supply network was planned and developed as a 'dual system', providing different conditions of access to people residing in different parts of the capital (Rusca et al., 2017b). Urban planners were concerned with the elevated costs of providing infrastructure and basic services for all. This challenge, which they described as one of a 'technical nature' (Matope, 1984), was dealt with by developing a more sophisticated system with in-house connections in high and middle-income areas around Capital Hill and the parliament buildings, whilst the traditional housing areas and the urban spaces developed for lower-income residents were served by water kiosks spaced at 1000 feet distance one from the other (Englund, 2002). Further, the informal unplanned settlements, which grew mostly in the southern part of the city, were purposefully kept out from the core urban infrastructures (Myers, 2003). In 1972, for instance, the water treatment capacity was increased to produce an additional 1750 m³ per day (SAFEGE, 2002d). In addition, two service reservoirs were constructed in the northern Zone at Mtunthama and another at Kanengo (LWB, 2008), whilst the unplanned settlements in the South were excluded (Figure 3b).

Supporting the growth of the city: Extra water for premium users

In 1978, the water treatment capacity was further expanded to produce 8000 m³ of additional extra water per day. Along with this increase in treatment capacity, the network was expanded towards the central and northern parts of the city through three new service reservoirs. In addition, a new service reservoir was constructed further northwards at Lumbadzi in 1980, primarily to support developments around the newly planned Kamuzu International Airport, which was inaugurated in 1983. During the same period, only the Tsabango Service Reservoir was constructed for the Southern Zone (Figure 3c) and its main aim was to serve two important government institutions: the Malawi Defence Force headquarters, known as Kamuzu Barrack, and the presidential palace of Kamuzu Banda, popularly known as State House, respectively, located in Area 35 and Area 44 (LWB, 2008). This extension, therefore, does not represent a deviation from the expansion strategy of the past decade: although most of the population growth was occurring in the South, mainly in unplanned settlements, the extra water produced was benefitting the Central and Northern parts of the city and the premium users in the South.

The uneven distribution of infrastructures and the inequality in their capacity to supply water across the city are well expressed by the skewed distribution of service reservoir storage capacity over the zones- by 1987, the Central Zone had 15,910 m³ of service reservoir storage capacity to distribute water for a population of 42,871 while for the population of 120,343 in the Southern Zone, the storage capacity of service reservoirs was only 6820 m³ (see Figure 2).

Figure 2. Comparison of zone-wise service reservoir storage capacity⁶ and population in 1987.



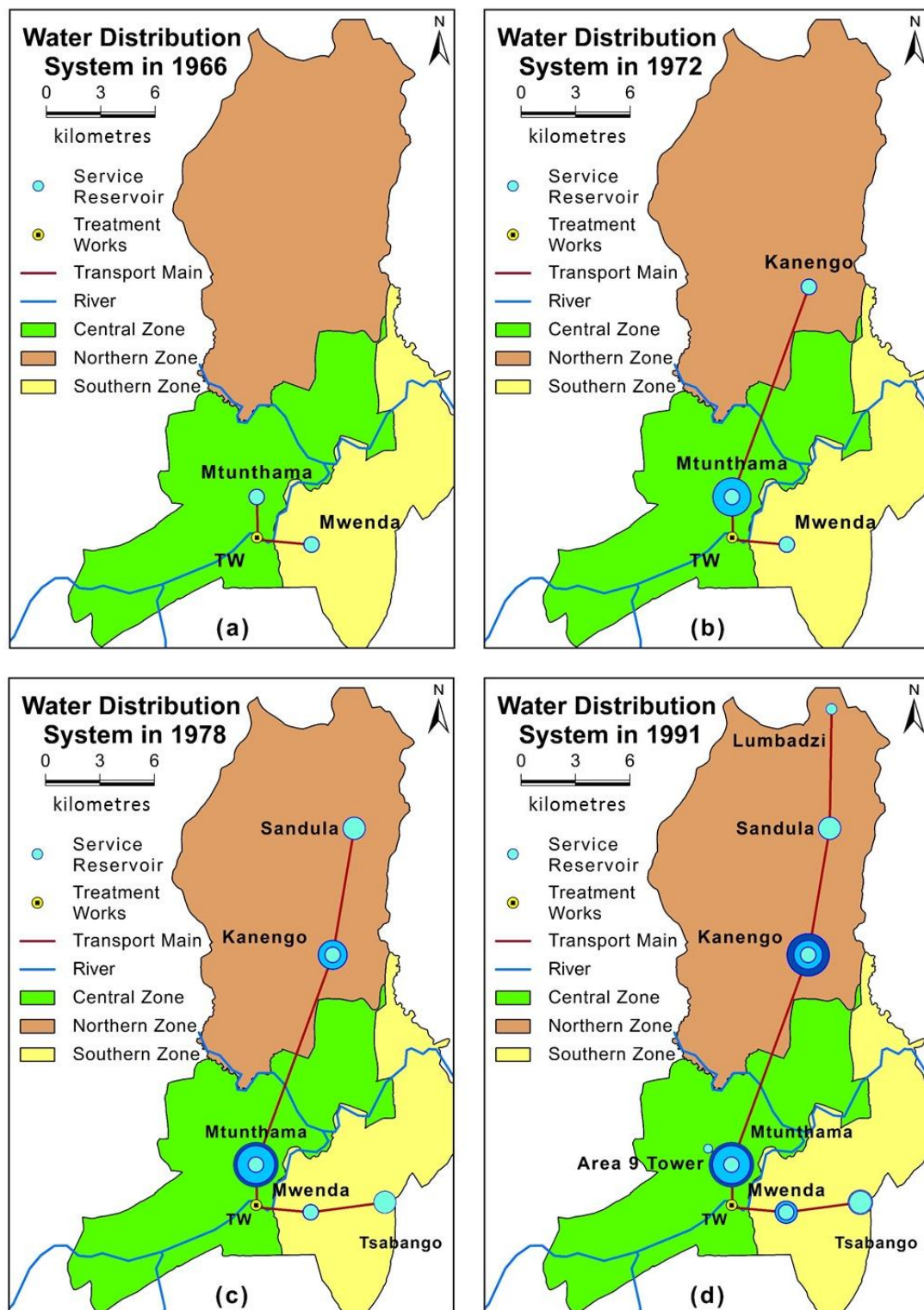
The systematic prioritisation of the Central and Northern Zones continued with the Second Lilongwe Water Supply Project (2nd LWSP), implemented with the financial support of the World Bank between 1986 and 1993. Under this project, the Kamuzu Dam-II, with a capacity of 8.9 Mm³, and an additional treatment plant with a capacity of 27,000 m³/day were constructed (World Bank, 1986). Yet, once again the incremental improvements to the network which followed the production of this extra water only exacerbated existing inequalities in water supply and conditions of access. In 1991, the supply system was upgraded with four new service reservoirs (LWB, 2008). The two reservoirs built in the South have a total capacity of 2650 m³, whilst the two constructed for the Central and Northern Zones have a total capacity of 8150 m³ (Figure 3d).

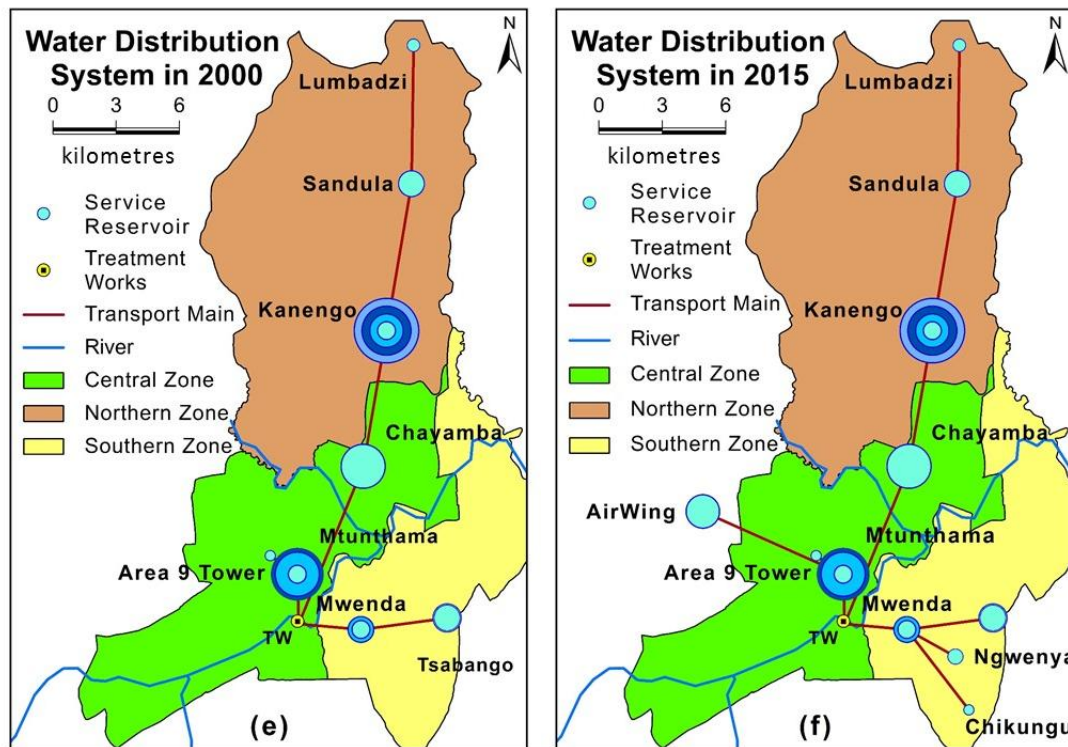
Reaffirming differentiated water distribution: Extra water in the multi-party era

In 1994, Malawi shifted from a single party regime to a multi-party system. The strategy of developing water infrastructures for the Central and Northern Zones, to the neglect of the Southern Zone, was reaffirmed by the new government. The Third Lilongwe Water Supply Project, inaugurated in 1998 and supported by the World Bank, raised the Kamuzu Dam-II by five metres, thereby increasing its capacity from 8.9 Mm³ to 19.6 Mm³ (SMEC, 1993). Moreover, the project constructed a new water treatment plant with a capacity of 33,000 m³/day (SAFEGE, 2002d). In 2000, with the construction of two additional service reservoirs, network expansion once again took place in the Northern and Central Zones, at Kanengo (10,600 m³ capacity) and Chayamba (12,000 m³ capacity), respectively (Figure 3e) (LWB, 2008). So far, Chayamba is the largest service reservoir in the city.

⁶ The zone-wise service reservoir storage capacity is calculated by summing up the storage capacity of all the service reservoirs located within the zone. For example, there were two service reservoirs in the Southern Zone of capacity 2275 m³ and 4545 m³; therefore, the total storage capacity was 6820 m³.

Figure 3(a-f). Maps indicating incremental growth of primary distribution network from 1966 to 2015 (size of symbol of service reservoir is proportional to its storage capacity).





Between 2000 and early 2015, when the field work for this study was carried out, no additional extra water had been produced. The only measure undertaken to address the growing demand of the southern part of the city was the construction of two new service reservoirs in Ngwenya in 2006 and Chikungu in 2013 (Figure 3f). The developments between 1998 and 2015 have, therefore, maintained the status quo by allocating lowest storage capacity to the highly populated Southern Zone as compared with the Northern and Central Zones (see Figure 4).

The transport main is another infrastructural component of the water supply network governing the flow of extra water and contributing to the inequities in water distribution across zones. Primarily, the water-carrying capacity of the transport main is determined by its diameter.⁷ There are large differences in the diameter of the transport mains that connect the three zones, with the transport mains distributing water to the Northern and Central Zones having larger equivalent diameters (800 mm and 625 mm, respectively) than those in the Southern Zone (467 mm). As a result, the water-carrying capacity⁸ towards the Northern and Central Zones is respectively 3 times and 1.8 times higher than that of the Southern Zone (see Figure 5a).

⁷ The water-carrying capacity of the transport mains depends on two parameters - its diameter and the velocity of water in the transport main. The principal design criterion followed by the Lilongwe Water Board (LWB) for the sizing of the transport mains is that the maximum velocity of water should not exceed 1.5 m/s to avoid excessive head loss and operational cost (SAFEGE, 2002b). With a higher velocity of water in the transport main, more energy is required to push the water causing higher operational costs. Given this criterion of limiting the velocity, the diameter of the transport main is the only physical parameter determining how much maximum water it can carry and distribute to different parts of the city.

⁸ Though, diameter determines how much water can flow, for comparing water-carrying capacity, the area of cross section of pipe or area of cross section corresponding to equivalent pipe diameter is considered for calculation. The area of cross section measures more appropriately the carrying capacity of the pipe.

Figure 4. (a) Comparison of zone-wise service reservoir storage capacity till 2000 and population according to the 1998 census; (b) Comparison of zone-wise service reservoir storage capacity till 2015 and population according to the 2008 census.

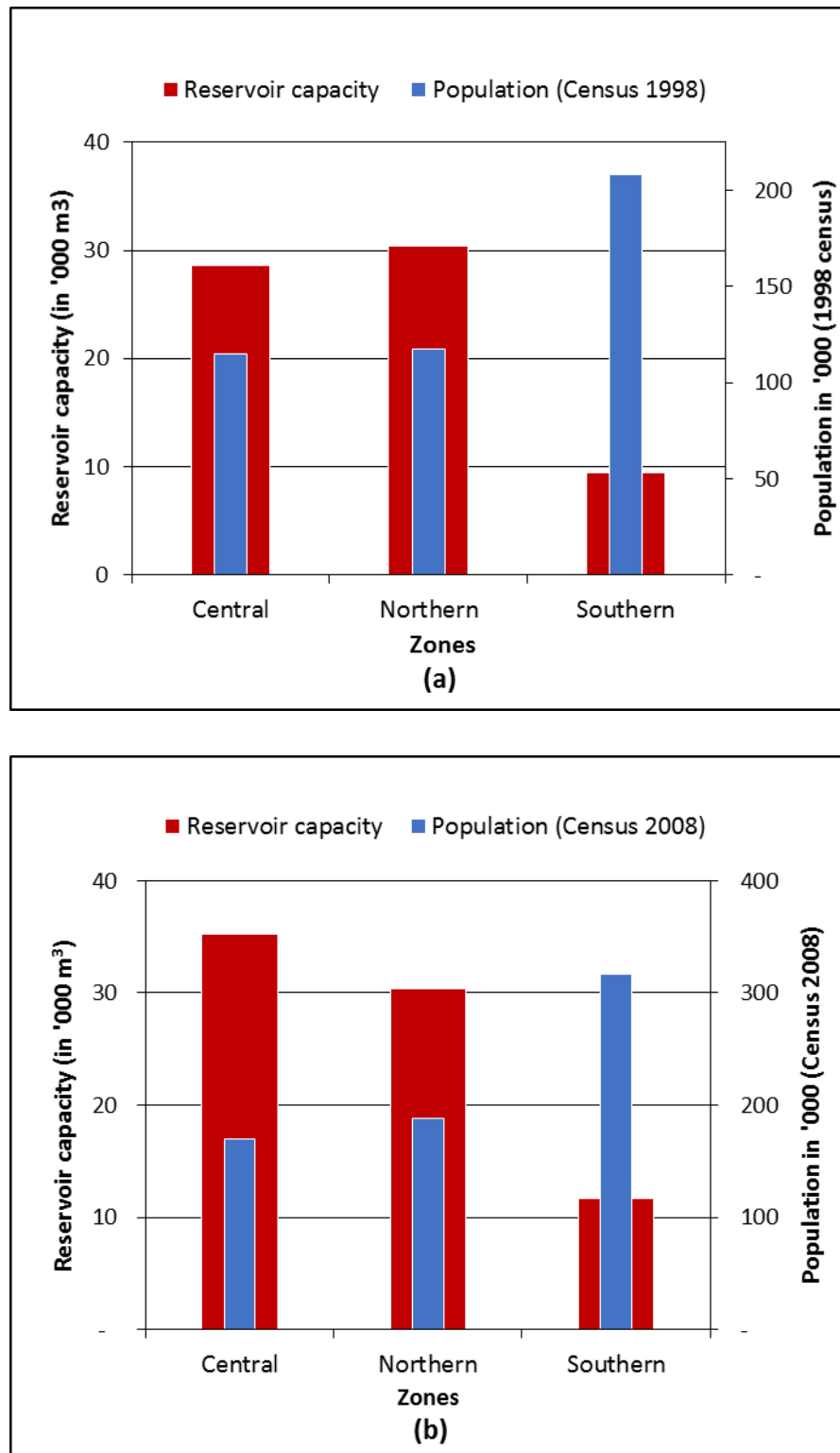


Table 1. Average daily production of water at treatment works, zone-wise quantity of water pumped and availability of water in gross lpcd over years (SAFEGE, 2002e; LWB, 2003, 2007).⁹

S. No.	Year	Average daily production of water (m ³ /day)	Southern Zone		Central Zone		Northern Zone	
			Quantity pumped (m ³ /day)	Gross LPCD available	Quantity pumped (m ³ /day)	Gross LPCD available	Quantity pumped (m ³ /day)	Gross LPCD available
1	2001	57,706	13,224	64	21,161	184	23,321	198
2	2003	57,286	12,397	60	23,787	207	21,102	180
3	2007	62,344	11,333	36	29,978	176	21,033	112
4	2012	92,201	21,640	68	32,545	192	38,016	202
5	2014	95,716	27,661	87	33,727	199	34,328	182

To ascertain the influence of the transport main dimensions and the direction of the network extensions on water distribution, we looked at the figures of bulk water distribution across zones (see Table 1). These figures show water distribution patterns in different zones between 2001 and 2014 in gross litres per capita per day (lpcd). As the Southern Zone has been consistently receiving less water, the figures confirm that the smaller size of the transport main and the lesser service reservoir storage capacity limit the water-carrying capacity of the Southern Zone during operations.

In sum, whilst the past five decades saw a production of extra water of 92,500 m³/day (from 2,500 m³/day to 95,000 m³/day), much of this extra water has benefited the places and people that were already receiving relatively good services. Those without satisfactory conditions of access remain underserved. To illustrate this point, in the southernmost corner of the city, where Judith resides, over 40,000 residents are served only by the Chikungu Service Reservoir (LWB, 2011) and receive an average of 412 m³ per day, merely 10 lpcd (see Figure 5b).

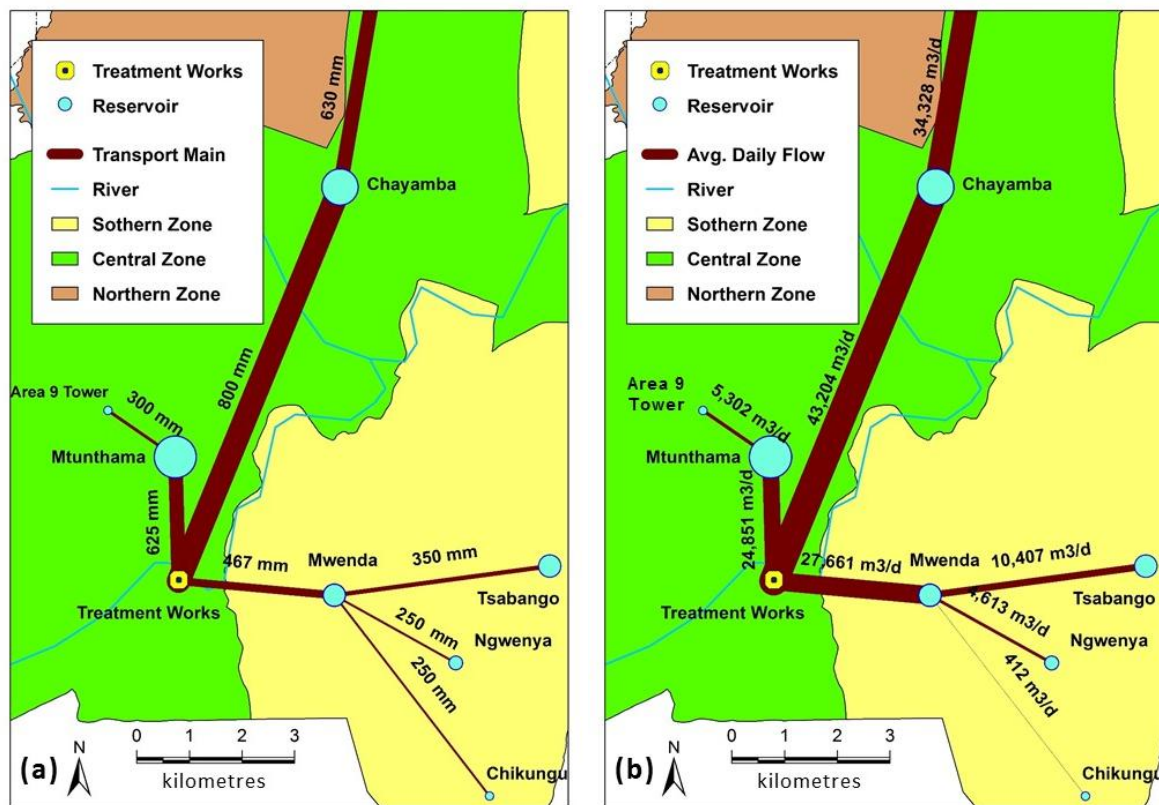
The planning and construction of differentiated infrastructures within the centralised water supply network, we argue, is a material and tangible proxy of the political priorities and goals of the Lilongwe City Council and the Lilongwe Water Board. An engineer from the planning department of LWB, when asked for the reasons of the excessive infrastructural provisions for carrying more water towards the selected zones over the years, responded as follows:

the Central Zone is important. Many government offices are located there. We are serving there all-important people including our bosses. We have to supply them water for 24 hours. (...) so, we need to ensure that all our pipes and service reservoirs are full with water all the time. (...) for people living in low-income areas, they have alternatives like wells and handpumps.¹⁰

⁹ Gross LPCD figures are approximately calculated by taking ratio of quantity of water pumped into the zone and total population of the zone available for the nearest census year.

¹⁰ Interview, Lilongwe Water Board engineer, Lilongwe, November 19, 2014.

Figure 5. Maps indicating (a) major transport mains connecting to service reservoirs depicting physical water-carrying capacity (thickness of the transport main is proportional to the water-carrying capacity of pipe) and (b) average quantity of water flowing daily (in m³/day) towards major service reservoirs in October,¹¹ 2014 (thickness of line is proportional to the quantity of flow).



As Alda-Vidal et al. (2018) suggest, the prioritisation of certain areas and consumers is rationalised through the idea of the so-called 'premium customer', a citizen who needs and deserves more water than others. Premium customers are not pre-existing operational categories. During operations, field-level engineers comply with the orders of their superiors and divert more water to the better-served areas. Through the routinisation of such practices, the provision of quality services to selected consumers becomes part of the normal responsibilities of engineers. This is how premium users are discursively and materially constructed. As a higher official from LWB contends, the central zone is a 'strategic' area and needs to be well served even during periods of water shortages: "how do you feel if a minister picks up the phone and tells you that there is no water at his tap or if you receive a similar phone call from an embassy"?¹² The political pressure experienced by planners and designers of the Lilongwe Water Board is reflected in the oversizing of diameter of pipes and service reservoirs. The oversizing increases the carrying capacity of the pipes and the storage capacity of service reservoirs in the network and, in turn, enables field engineers to ensure excess and continuous supply of water (as high as 300 to 800 lpcd) in any circumstance – often to the detriment of other areas of the city.

¹¹ In Lilongwe, October is the hottest and driest month of the year (before an onset of wet season stretching over November to April).

¹² Interview, Higher Official, Lilongwe Water Board, Lilongwe, December 4, 2014.

Higher officials pass these political pressures on to ground level staff who operate and maintain the network on a daily basis. Hence, field engineers operating the network feel compelled to comply with the demands of their superiors to prioritise certain areas and customers. As one of the operators explains, "if there is no water for a few hours, then those people (in high-income areas) complain a lot to our bosses. Sometimes, the General Manager directly calls and orders me to restore the supply immediately". Informal political networks explain why LWB staff are more concerned with serving premium users than with low-income areas, where "if there is no water even for 2-3 days then those people don't make a noise".¹³ When asked, the utility staff also justifies prioritisation of the Northern and Central zones by arguing that residents in low-income areas are more resilient and that "water is the least of the problems", whilst people in higher-income areas "use several devices which require the constant flow of water".¹⁴

CONNECTING CITIZENS TO THE EXTRA WATER

Last mile connectivity: Coverage versus access

'Last mile connectivity' is a term we use to refer to the end segment of the distribution network, the part that connects citizens to the dams. As it is through this last mile of the network, citizens are ultimately provided with physical access to water, it is, we argue, as important as the dam itself. Despite this, all major externally funded urban water supply infrastructure development projects including the 2nd and the 3rd Lilongwe Water Supply Projects – only focused on the construction of dams, treatment facilities, transport mains and service reservoirs, leaving the question of the last mile connectivity to the LWB to resolve (Stanley, 1986; SMEC, 1993).

This has led to a paradox: while planning the dams for Lilongwe, the current and future water demand of *all* citizens was considered. Hence, the size of the dam was calculated and justified on the basis of these numbers (Stanley, 1986; SAFEGE, 2002c; SOGREAH, 2010a). Yet, after the dams were constructed only some selected citizens were connected and able to receive water. This is because the planning of the distribution of the extra water produced by the dam stopped at the service reservoirs, almost as if that water would find its own way from these reservoirs to the doorsteps of residents.

According to the consultancy firm Stanley International, one of the rationales for raising the Kamuzu Dam-II (1998) was meeting the demand (calculated at 128 lpcd) of the citizens living in unplanned settlements (Stanley, 1986). The design report thus mathematically and discursively connected these residents to the extra water of the dam. This mathematical plan never materialised into a physical water connection for the residents living in these areas. While Judith's demand of 128 lpcd was explicitly included while sizing the dam, and even though the needed quantity of water was stored in the dam in her name, the design and construction of the distribution network did not allow for the calculated 128 litres per day of water to be transported to Judith's doorstep. Nor did it for all the other people living in the unplanned settlements.

For planned areas, the secondary and tertiary networks are financed by the Malawi Housing Corporation (MHC), the Lilongwe City Council (LCC), or the Ministry of Land and Urban Development, who own the land in the city. These agencies pay the Lilongwe Water Board upfront for the development of the distribution network and, in some cases, even for the laying of major distribution mains (LWB, 1997). In these planned areas, water services are, thus, supply-driven and the costs are passed on to the future house owners. For unplanned settlements, like the one Judith lives in, there are no funds set aside for the expansion of the distribution network. Earlier, large infrastructural

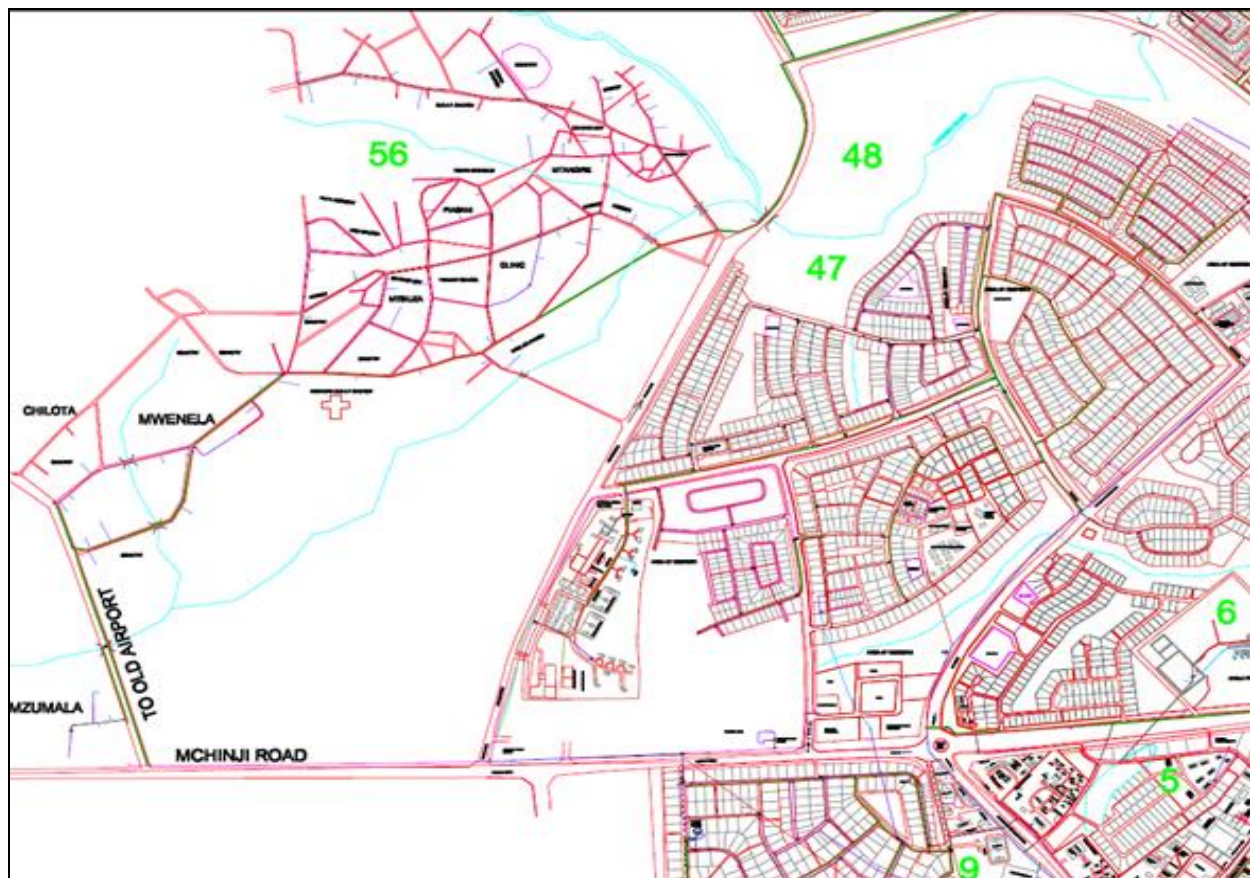
¹³ Interview, Lilongwe Water Board Operational Staff, January 6, 2015.

¹⁴ Interview, Lilongwe Water Board Operational Staff, Lilongwe, October 6, 2014 in Alda Vidal et al. (2018).

development projects did not budget for the last mile connectivity in these unplanned settlements, nor is any government agency held responsible for investing in the extension of the network towards unplanned settlements. Expanding the network to unplanned areas is left to the Lilongwe Water Board, which mostly relies on the financial support of the NGOs dealing with access to basic services.¹⁵

These NGOs finance - kiosks and connections to the centralised water supply network. Yet, as kiosks are only open a few hours per day, far away and often very busy, they provide an intermittent supply of water to the residents of unplanned settlements, limiting their ability to benefit from the extra water. As a resident of Area 56 explains, "the bucket is not something cultural, it is everyday life (...) if we would have water the whole day we would not need to have buckets, then we could go straight to the source" (in Rusca et al., 2017a).¹⁶ In addition and paradoxically, as the network is less developed in these areas, the connection fee for a yard tap or in-house connection is higher than in higher-income areas and reaches up to USD100-120. This is because these households need to pay the cost of extending the pipe to their own yard. The implication is that very few people living in low-income areas can afford an in-house connection and are able to improve their conditions of access.

Figure 6. Spread of distribution network in unplanned settlement of Area 56 and in planned settlement of Area 47 of Lilongwe (LWB, n.d.)



¹⁵ For additional information on the role of NGOs and CBOs in negotiating access for low-income areas refer to Rusca and Schwartz (2012).

¹⁶ Interview Resident Area 56, Lilongwe, February 2016, in Rusca et al. (2017a).

The absence of the last mile connectivity is clearly visible from the map of the distribution network of Area 56, a low-income informal neighbourhood located on the western fringe of the city, and the adjacent planned settlement in Area 47 (see Figure 6). Area 56 has a population of 36,642, but the network is composed of a single pipe with a diameter of 160 mm. Residents are mainly supplied via kiosks. Area 47, on the contrary, has a population of 8139, and is fed with five different pipes ranging from 200 mm to 150 mm in diameter (Velzeboer, 2018). As a result, women from Area 56 must often walk to Area 47 to ask for water and carry heavy buckets back to their homes.

Five decades of infrastructural developments: Who benefits?

Today Lilongwe is the largest and fastest growing city in Malawi, with a population expected to have reached (from a mere 20,000 in 1966) a million in 2015 (NSO, 2008; UN-HABITAT, 2011). Even though growing slightly more slowly, the increase in water supply capacity is also tremendous, from 2250 m³/day to 95,000 m³/day over the last five decades. In theory, the amount of total water produced is sufficient to ensure universal coverage (Figure 7). Yet, the city's centralised water supply network only serves 78% of the population, of which only 44% are served through in-house connections and 56% rely on water kiosks.

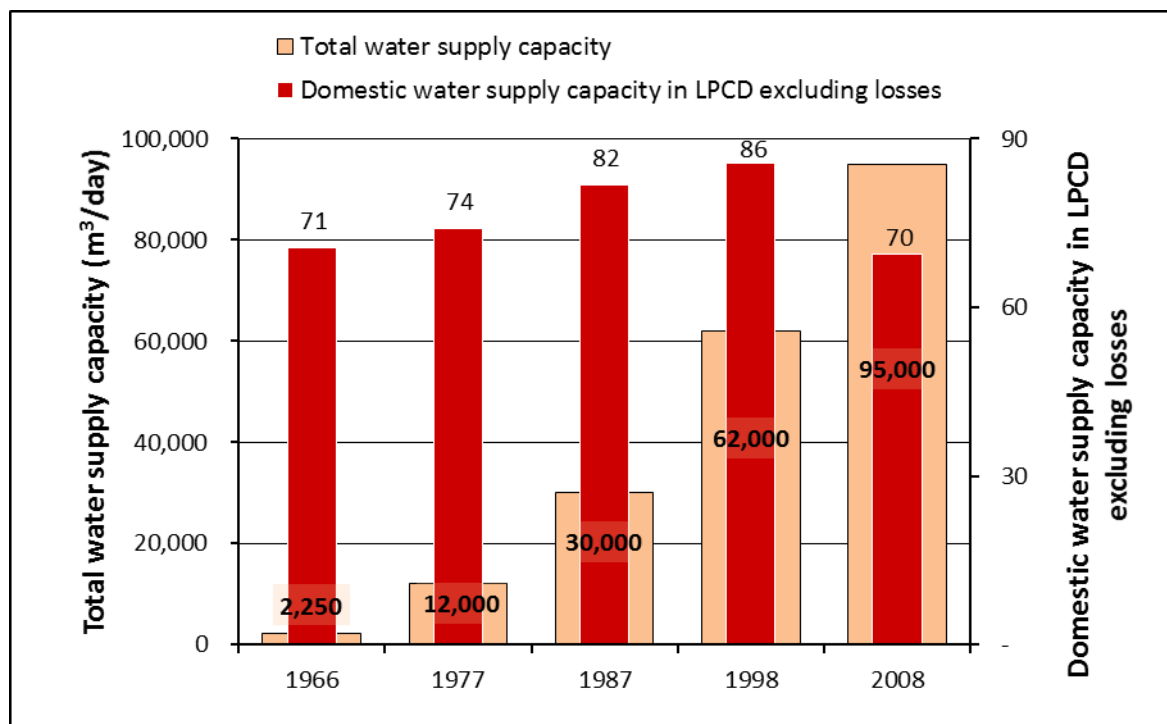
In 2008, for instance, of the total built water supply capacity of 95,000 m³/day, 29.9% was lost in the distribution network,¹⁷ while an amount of 19,719 m³/day was allocated to non-domestic water use (SOGREAH, 2010b). Therefore, an amount of 46,876 m³/day was available for domestic use for the population of 674,448 (NSO, 2008). Theoretically, this means around 70 lpcd would have been available to each and every individual every day at tap level, a number that is well above the estimated average per capita per day consumption of 64 lpcd considering all categories of users as per the demand assessment report prepared by LWB in 2010 (SOGREAH, 2010b). However, in reality in 2008, only 44% of the total population was enjoying in-house piped connections, 14% of the residents were using kiosks and consuming only an average of 24 lpcd and the remaining 40% of the population was not at all connected to the network (SOGREAH, 2010b).

A comparative analysis of the billing data of domestic consumption – including individual connections and kiosks – of 1998 (before Kamuzu Dam-II was raised) with that of 2008 (ten years after raising it¹⁸) confirms that a major portion of the 10.7 Mm³ of extra water was diverted towards the Central Zone – the zone where ministers, government officials and expats reside (Figure 8). Figure 8 compares the lpcd consumption for each area¹⁹ and confirms that significant differences exist between the residential areas of the Southern and Central zones.

¹⁷ In 2008, the total non-revenue water (NRW) was 37.7% with 7.8% losses in water treatment process and 29.9% in the distribution network.

¹⁸ We believe a period of ten years is quite sufficient to appropriately distribute the benefits of the increasing storage capacity of the dam by making necessary upgradation in the distribution network.

¹⁹ The lpcd consumption for each area is calculated by taking the ratio of the average quantity of domestic water (individual connections and kiosks) billed per day in a given area to the population of the area before and after the raising of the Kamuzu Dam-II.

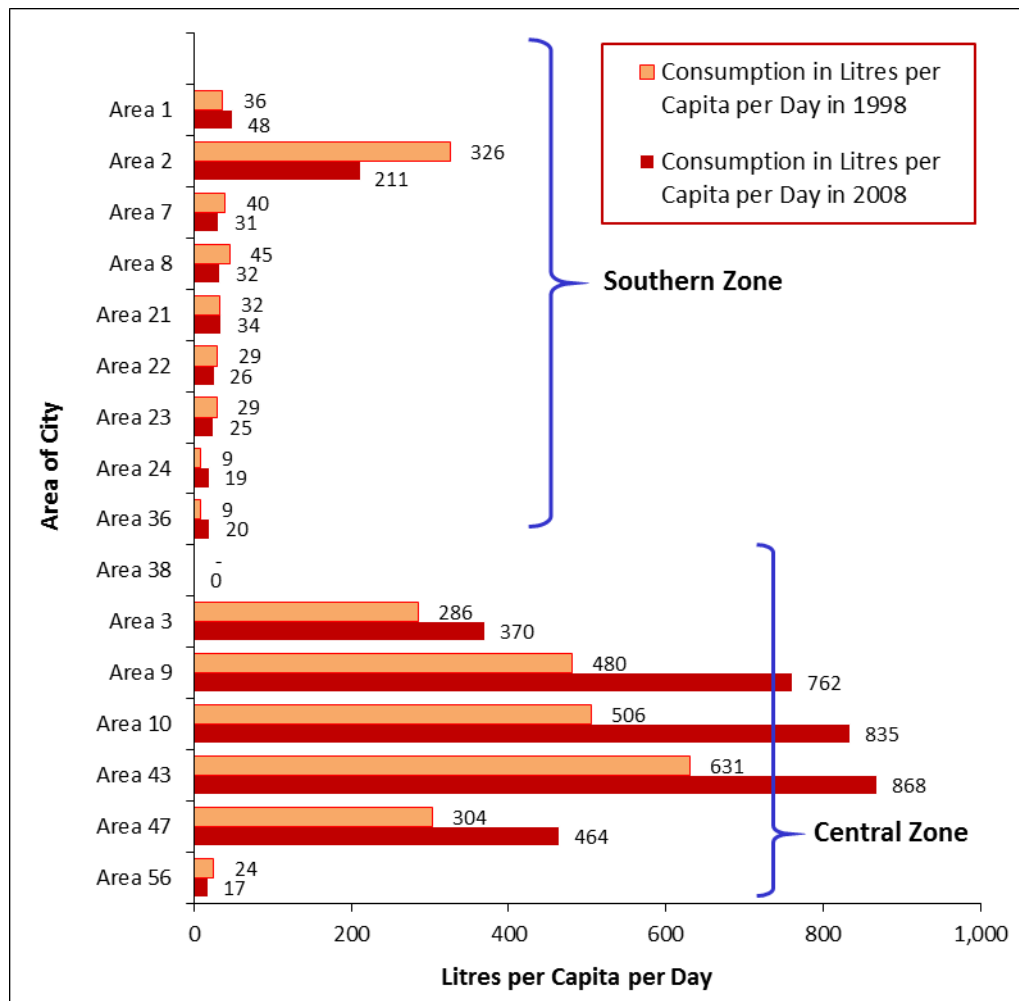
Figure 7. Total water supply capacity and domestic water supply capacity in lpcd excluding losses.²⁰

Sources: SAFEGE, 2002d; JICA, 2010; SOGREAH, 2010b.

The per capita consumption in the Central Zone increased significantly after extra water was made available to the city. The increase in consumption in Areas 3, 9, 10 and 47 was respectively 29, 59, 65 and 53%. Consumption rates in these areas, which were already higher in 1998, thus became even higher in and after 2008. In Area 9, for instance, consumption increased from 480 to 762 lpcd and, similarly, in the case of Area 43 it rocketed from 631 to 868 lpcd in 2008. These values of consumption are way higher than the standard of 135 lpcd set by LWB (SOGREAH, 2010b). On the contrary, areas in the south suffering from poor coverage and served mainly through kiosks did not gain much from the availability of extra water. Paradoxically, in wealthier neighbourhoods, where water is provided with high continuity and reliability through in-house connections, it is partially subsidised. In contrast, in low income areas, where service is unreliable and intermittent, mainly through kiosks, the residents pay up to twice as much for water (Rusca and Schwartz, 2018).

²⁰ We calculated per capita per day domestic water available by taking the ratio of total domestic water supply available to the total population of the city. This results in the quantity of water that was theoretically made available to the entire population of the city, irrespective of coverage and supply standards. For year 2008, the quantity of domestic water supply is calculated by deducting actual non-domestic usage including industrial, commercial and institutional use and losses from water supply capacity. For the remaining years, since the data of non-domestic use is not available, it is considered as 15% of domestic demand as suggested by JICA (2010) in the Master Plan of Lilongwe.

Figure 8. Comparison of litres per capita per day (lpcd) consumptions in year 1998 and 2008 in residential areas of Southern and Central Zone of the city.



CONCLUSION

This study illustrates the importance of taking materiality seriously when examining and characterising urban water inequities. Examining and tracing the technical intricacies of the water supply network and its development over time shows how the investments in the production of extra water (dams and treatment plants) mostly benefit those who are already better served. This happens even when these investments were originally justified as ways of better meeting the water needs of unplanned settlements, or those with poor conditions of water access. The material properties of the network – direction, dimension and last mile connectivity – enact the systematic prioritisation of socio-political influential spaces of the city in terms of water provision. These also explain how Judith and many other people in the city have benefitted much less from the extra water produced. The meticulous mapping of the design characteristics of networked water infrastructures, therefore, is a revealing entry-point into the politics of urban water management, helping lay bare the power and interests that are often concealed under discourses of universal access.

Our methodology of following the extra water is a tangible proposal for operationalising and giving meat to the currently widespread call for more attention to infrastructure in theorising and understanding uneven urban development. The methodology consists of mapping the city's water

inequities by analysing the two components of the network – pipes and service reservoirs – and their properties in terms of size of pipe, storage capacity of service reservoirs and their strategic locations in the city. Meticulously tracing how much water flows where offers tangible and measurable data on the production of water inequities in the city, moving from descriptions of water flows to quantities of water distributed and accessed by each citizen. In doing so, the production of the uneven waterscape has the potential to be captured by and 'speak' through different disciplinary perspectives.

Critical social sciences have convincingly shown how pipes are not just conduits of water but also of power, revealing how infrastructural developments are intertwined with political forces and co-determine socio-ecological inequalities (Anand, 2017; Rusca et al., 2017a; Swyngedouw, 2004, 1997). In many of these analyses, the infrastructure itself remains outside of proposals for change. Also, the actors and 'do-ers' behind the pipes – the engineers and operators – either remain relatively invisible or implicitly figure as always or necessarily allied with the powerful. Our disaggregation of the network in its multiple parts (pipes, service reservoirs, pumps and valves) and a careful examination of the functions and physical properties (material – GI, HDPE, MDPE, PVC, DI, CI; diameter, thickness, carrying capacity, type of flow – rising main or gravity main) draws attention to possibilities of re-directing, manipulating or modifying pipes and other water infrastructures as ways to make water provision more equitable or just. It thus usefully allows engaging with (rather than merely exposing or condemning) technology and infrastructure as the playing field of water politics. Doing this may include developing meaningful collaborations and alliances with water supply engineers and network operators. By nature of their discipline and profession, they are already attentive to the physical properties of infrastructures. Indeed, for them, stating that water infrastructure is not fixed is a truism: designing, analysing changing and tinkering with the technical is, after all, their job.

Last, while not the focus of the paper, the case of Lilongwe also raises important questions on the relationship between political regimes and inclusive basic service provision, shedding a revealing light on the agency of marginalised people in terms of how they respond to, and interact with, the materiality of the network. In this sense, our methodology may usefully complement and inspire analyses of the intricate relations between uneven water provision and the production and maintenance of state power (cf. Meehan, 2014). The questions raised here are aimed to stimulate new research directions to further critical water studies of water provisioning and access in and beyond urban environments.

ACKNOWLEDGMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement INHAbIT Cities, No 656738 and from the DGIS-UNESCO IHE Programmatic Cooperation under the Uncovering Hidden Dynamics in Slum Environments (UNHIDE) project.

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